Chapter 3 – The Science Content Standards
High School (Grades 9-12): Earth Sciences

INTRODUCTION

By looking outward into deep space and deep time, astronomers have discovered that we live in a vast and ancient universe. Earth science helps students find their own place in this universe by showing where our unique world fits in the grand scheme of the cosmos. Students of the earth sciences gain understanding of the physical and chemical processes that formed and continue to operate here on Earth. As they study these standards, students will also learn more about the geological factors that help make California special.

The sun, a rather ordinary star, provides virtually all the surface energy required for life on Earth. Its energy also drives convection in our atmosphere and oceans, which in turn drives global climate conditions and local weather patterns. Additionally, heat energy moves slowly below the earth's surface through the planet's interior. Some of this internal heat originated with the formation of the planet and some is generated by the decay of radioactive nuclides. Slowly this geothermal heat escapes to the hydrosphere and atmosphere. The quantity of geothermal heat is tiny compared to incoming solar energy. Over the long term, it is responsible for plate tectonic processes – moving continents, building mountains, volcanism, and earthquakes.

STANDARD SET 1: Earth's Place in the Universe (Solar System)

Background

Students should already have studied the star patterns in the night sky and how these patterns change with the seasons and lunar cycles. They also should have been introduced to the solar system, and can be expected to know that the sun is the center of the solar system and is composed primarily of hydrogen and helium. They should also know that the solar system includes the earth and eight other planets, their moons, plus a large number of comets and asteroids, and that the orbits of all these objects are primarily determined by gravitational interaction with the sun. From eighth grade, they should know something about the composition, relative sizes, positions and motions of solar system objects.

Students should become familiar with evidence that dates the Earth at 4.6 billion years old, and should know that our planet has been struck by extraterrestrial objects in the past. They also have learned that the Moon, planets and comets all shine by reflected light. For this standard set, students will need to bring an understanding of electromagnetism and gravity. Students should know and understand the Doppler effect, and the inverse square law of light (HS Physics Standard Set 4f). Familiarity with acquisition and analysis of spectral data will also be helpful. When presented with the content in this standard set, students may find it difficult to grasp the vastness of geologic time and astronomical distances. Teachers should provide opportunities for students to think about space and time in different scales from the macroscopic to the microscopic. This ability comes, for many students, with practice in working with the numbers, and by developing an ability to visualize the system in the appropriate scale.

Description of the Standards

1. <u>Astronomy and planetary exploration reveal the solar system's structure, scale, and change over time.</u> As a basis for understanding this concept:

a. Students know how the differences and similarities among the Sun, the terrestrial planets, and the gas planets may have been established during the formation of the solar system.

This standard relates to how the Sun and planets formed and developed the characteristics they have today. It is believed that the Solar Nebula, a slowly rotating massive cloud of gas and dust, contracted under the influence of gravitational forces and eventually formed the Sun, the rocky inner planets, the gaseous outer planets, moons, asteroids and comets. The exact mechanism by which this happened is unknown. The outer planets are condensations of lighter gases that were blown to the outer solar system by solar winds at the time the sun's fusion reaction ignited. This theory is supported by the observations that the orbital planes of the planets are nearly the same, and that the planets revolve around the Sun in the same direction.

To understand the vast size of the solar system, students will need to understand scale, know the speed of light, and be familiar with units typically used for denoting astronomical distances. For example, Pluto's orbital radius can be expressed as 39.72 AU or 5.96×10^{12} meters or 5.5 light-hours. An AU, or astronomical unit, is a unit of length equal to the mean distance of the Earth from the sun, approximately 93 million miles. A light year is the distance light can travel over the course of one year, through a vacuum, and is approximately 5.88 trillion miles or 9.46 trillion kilometers. To help students visualize the vast distances in the solar system, the relative size of the planets and their orbit around the Sun, students can make a scale model. Calculator tape may be used to plot these distances to scale.

b. Students know the evidence from Earth and moon rocks indicates that the solar system was formed from a nebular cloud of dust and gas approximately 4.6 billion years ago.

Geologists, through relative dating techniques, have known since the nineteenth century that the earth is very old. Relative dating methods, however, are insufficient to put an actual date on events in the deep past. It took the discovery of radioactivity to provide science with a "clock." Radioactive dating of terrestrial samples, lunar samples and meteorites indicates that the Earth/Moon system and meteorites are all approximately 4.6 billion years old.

The solar system formed from a nebula, a cloud of gas and debris. Most of this material consisted of hydrogen and helium created during the big bang, but it also included heavier elements that were formed by nucleosynthesis in massive stars that lived and died before the sun was formed. Star death can result in a spectacular explosion called a supernova, in which debris rich in heavy elements is ejected into space as stardust. There is strong evidence that the collapse of our solar nebula was triggered by the addition of stardust from a nearby supernova. The collapse of a nebula leads to heating, increased rotation rate and flattening. From this hot, rapidly spinning nebula emerged the sun and solid grains of various sizes that later accreted to form objects that evolved through collisions into planets, moons, and meteorites. The nebula from which the sun and planets formed was primarily hydrogen and helium, and our solar composition reflects this starting mixture. The nebula also contained some heavy elements. As it cooled, condensation of the heavy elements and loss of volatile elements from the hot, inner nebula led to formation of rocky inner planets. The cooler, outer solar system was less fractionated and consequently is richer in more volatile lighter elements.

c. Students know the evidence from geological studies of Earth and other planets suggest that the early Earth was very different from Earth today.

The prevailing theory today is that Earth formed around 4.6 billion years ago by the gravitational accretion, or contraction, of gases and dust grains found in a portion of the solar nebula. As it accreted, matter was heated by gravitational compression and the kinetic energy released by impacting debris and planetoids. Eventually, the interior of the planet heated sufficiently for iron, a very abundant element in the earth, to melt, and its high density caused it to sink toward the center of the earth. The lower density materials rose and differentiated, volatile gases "burped out"; this gave birth to the differentiated, layered Earth, with its characteristic layers of core, mantle, crust, and oceans/atmosphere. The earth has been slowly cooling since its formation, although radioactive decay has provided additional heat.

Evidence from drill core samples and surface exposures of very old rocks provides evidence that early Earth differed from today in the distribution of water, composition of the atmosphere, and the shapes, sizes and positions of land masses. Knowing about the evolution of these systems will help students understand the structure of the earth's lithosphere, hydrosphere, and atmosphere.

The earliest atmosphere was probably very similar to the composition of volcanic gases today, consisting mostly of water vapor, hydrogen, hydrogen chloride, carbon monoxide, carbon dioxide, and nitrogen, but with essentially no free oxygen. Therefore, there was no ultraviolet-absorbing ozone layer in the stratosphere, and ultraviolet radiation from the sun would have kept the surface of the planet sterile. The oldest fossils are of anaerobic organisms, and indicate that life on our planet was established sometime before 3.5 billion years ago. Conditions on our planet were suitable for life to originate here, but the possibility that life hitched a ride to Earth on a meteorite cannot be excluded.

The continents have slowly differentiated by partial melting of rocks, with the lightest portions floating to the top. The absence of atmospheric oxygen permitted substantial quantities of iron (ferrous) to dissolve, and some of this iron later precipitated as iron oxide (ferric oxide or rust) when early photosynthesizers added oxygen to the atmosphere. This precipitation of iron produced "banded iron formations," a geologic resource important to the contemporary world. These deposits were only formed during distinct time periods, generally from one to three billion years ago. Subsequently, atmospheric oxygen rose sufficiently to permit multi-cellular, aerobic organisms to flourish.

d. Students know the evidence indicating that the planets are much closer to Earth than the stars are.

Observations of planet motions relative to the seemingly fixed stars indicate that planets are much closer to the earth than are the stars. Direct techniques for measuring distances to planets include radar, which makes use of the Doppler effect. Distances to nearby stars can be made using parallax, a technique that relies on trigonometry through the small angle approximation and on knowing the earth's orbital diameter around the Sun. For more distant stars and extragalactic objects, indirect methods of estimating distances have to be used, all of which depend on the inverse square law of light, which says the intensity of light observed falls off as the square of the distance from the source.

Student learning activities can include daily observations of the position of the Sun relative to a known horizon, observations of the Moon against the same horizon and also relative to the stars, and observations of planets against the background of stars. Relative distances of the Sun and the Moon can be estimated from eclipses if their sizes are known. Other activities can take advantage of existing positional data for planets, computer-based lab exercises, and simulations that incorporate the use of library media center resources.

e. Students know the Sun is a typical star and is powered by nuclear reactions, primarily the fusion of hydrogen to form helium.

Comparing the solar spectrum to those of other stars shows that the Sun is a “typical” star. Analysis of the spectral features provides information on the chemical composition and relative abundance of elements. The most abundant element in the Sun is hydrogen. The Sun’s enormous energy output is evidence that the Sun is powered by nuclear fusion, as this is the only source of energy that can produce the calculated total luminosity of the sun over its lifetime. Fusion reactions in the sun convert hydrogen to helium, and also some heavier elements. This is one example of nucleosynthesis, in which the fusion process builds helium and other elements (HS Chemistry Std.Set 11. c).

f. Students know the evidence for the dramatic effects that asteroid impacts have had in shaping the surface of planets and their moons and in mass extinctions of life on Earth.

Asteroid impacts have created extensive cratering on the Moon and on Mercury as well as other bodies in the solar system. Some craters can also be observed here on Earth, but most have been destroyed by the active erosion of our planetary surface. Some large impacts have had dramatic effects on the earth, planets and their moons. An asteroid impact is believed by many to have produced the unusual iridium-rich layer, at the boundary between the rocks of the Cretaceous and the Tertiary periods. This may have been ultimately responsible for the episode of mass extinction 65 million years ago, which caused the disappearance of the dinosaurs and many other species.

Simulations of asteroid impacts can be introduced either by video or classroom demonstration. Cratering can be modeled by carefully throwing marbles of different masses into soft clay or flour at different velocities. Students can observe the patterns of impact and crater shapes to help understand physical evidence for impact cratering gathered on the Earth and Moon. Using the mass and velocity of the striking object, students can estimate the energy released from crater impacts.

*g. * Students know the evidence for the existence of planets orbiting other stars.*

Spectral observations and direct imaging of nearby stars show that other stars have planetary systems. By the end of the year 2000, some 50 extra-solar planets had been detected. Methods used in these planetary discoveries rely on observing slight oscillations in the central star’s spatial position (astrometry) or in velocity shifts of spectral lines (Doppler spectroscopy). Students can search school and public library collections and appropriate Internet sites for current information about planetary exploration and discoveries of planetary systems.

STANDARD SET 2*:* Earth's Place in the Universe (Stars, Galaxies, and the Universe)

Background

For many students, high school earth science will be their first experience with using physical evidence to consider models of stellar life cycles and the history of the universe. In earlier grades, students should have observed the patterns of stars in the sky and learned that the Sun is an average star located in the Milky Way galaxy. Students also should have been introduced to astronomical units (AUs) to measure distances between solar system objects such as the Earth and Jupiter. Students should know that distances between stars, and also between galaxies, are measured in parsecs. The parsec is defined as the distance at which one astronomical unit subtends one second of arc. This distance turns out to be about 3.26 light-years. The concepts dealt with in this standard set are not part of daily experience for students. As in the previous standard set, students may need help to internalize the distance and time scales needed to describe the universe. Additionally, misconceptions derived from outdated hypotheses or from science fiction movies, books and videos may interfere with developing understanding of accepted scientific evidence. School libraries should try to keep their collections up to date. There has been a significant amount of new data as a result of space exploration in the last 20 years.

Description of the Standards

2. <u>Earth-based and space-based astronomy reveal the structure, scale, and changes in stars, galaxies, and the universe over time.</u> As a basis for understanding this concept:

a. Students know the solar system is located in an outer edge of the disc-shaped Milky Way galaxy, which spans 100,000 light years.

The solar system is a tiny part of the Milky Way Galaxy, a system containing gas, dust and billions of stars, all held together by gravity. Determining the shape of our galaxy is like reconstructing the shape of a building from the inside. Our conception of the Milky Way galaxy as a disc-shape spiral galaxy with a bulging spherical center of stars is obtained by noting the location of stars in the galaxy. If the Milky Way could be viewed under low-powered telescope from a planet in another galaxy, it would look like a fuzzy patch of light. Viewed with more powerful telescopes from that far planet, it would look like a typical spiral galaxy. About 100,000 years traveling at the speed of light would be required to go from one edge of our galaxy to the opposite side.

b. Students know galaxies are made of billions of stars and comprise most of the visible mass of the universe.

The large-scale structure of the visible, or luminous, universe consists of stars, which are found by the billions in galaxies. In turn, there are billions of galaxies in the universe, separated from each other by great distances and found in groups ranging from a few galaxies to large galaxy clusters with thousands of members. Superclusters comprise agglomerations of many thousands of galaxy clusters. Students should know that scientists catalog galaxies and stars by the coordinates of their positions in the sky, brightness, and other physical characteristics. Spectroscopic analysis of the light from distant stars indicates the presence of the same elements that make up nearby stars and our Sun, although the percentages of heavy elements may differ. Just as the sun is the most massive part of the solar system, stars are considered to make up most of the mass of the visible universe. In contrast, various forms of non-visible matter in the universe appear to make up most of the mass of the universe. The search for the dark matter contribution to the universe is at the frontier of astrophysics.

c. Students know the evidence indicating that all elements with an atomic number greater than that of lithium have been formed by nuclear fusion in stars.

Formation of the elements that comprise our universe is called nucleosynthesis. Theoretical calculations based on principles of nuclear physics have provided a likely scenario about how this has occurred, through the fusion of light elements to make more massive elements. Observations of stellar spectra that reveal their composition, as well as the abundance of different elements provide strong evidence that these theories are correct.

Models predict that the only elements that should have formed during the Big Bang are hydrogen, helium, and lithium. All other elements should have formed in the cores of stars through fusion reactions. Fusion requires that one nucleus approaches another so closely that they touch and bind together. This is difficult to accomplish because all nuclei are positively charged and repel their neighbors, creating a ‘barrier’ that inhibits close approach. However, the barrier can be bypassed if the nuclei have high velocities, attained at high temperature. Once the process gets started, fusion of light nuclei results in a net release of energy, facilitating further fusion. This mechanism can form elements up to iron. Temperatures sufficient to initiate fusion are attained in the cores of stars. In our sun, and in most stars, hydrogen fusion to form helium is the primary fusion reaction. Elements heavier than carbon are formed only in more massive stars, and only during a brief period near the end of their lifetime. A different type of fusion is necessary to form elements heavier than iron. This can only be carried out by adding neutrons to a pre-existing heavy element that forms a “seed”. Neutrons are available only during a limited portion of star’s lifetime, particularly during the brief supernova that occurs at the death of a massive star.

d. Students know the stars differ in their life cycles and that visual, radio and X-ray telescopes may be used to collect data that reveal those differences.

Stars differ in size, color, chemical composition, surface gravity and temperature, all of which affect the amount of energy emitted and its spectral composition. It is primarily the electromagnetic radiation emitted from the surface of the Sun and stars that we can detect and study. We utilize data collected by telescopes, which see in x-ray to radio wavelengths. This data enables astronomers to classify stars, determine their chemical composition, identify the stages of their life cycles, and understand their structures. Nobody has ever watched a start evolve from birth to death, but based on observations of many stars at different points in their cycles, astronomers can predict the ultimate fate of a given star. The primary characteristics that astronomers use to classify stars are surface temperature and luminosity (the total energy emitted).

e. Students know accelerators boost subatomic particles to energy levels that simulate conditions in the stars and in the early history of the universe before stars formed.*

Our understanding of processes occurring in stars has been enhanced by particle physics, nuclear physics and plasma physics experiments. Particle accelerators are used to create velocities large enough for nuclei of elements to overcome electrostatic repulsion and approach close enough for nuclear interactions to take place, mimicking stellar nuclear fusion processes. The first accelerator was developed in the 1950s in Berkeley, California. It allowed the energy of protons to be raised high enough to create antimatter particles, thereby making it possible to explore the substructure of what had been considered the most elementary form of matter. Scientists used the results from these experiments to create models of the processes and conditions under which matter is created. Einstein's Special Theory of Relativity, developed at the turn of the 20th century, showed that matter and energy are interchangeable. Particle accelerators made it possible to produce, in the laboratory, matter-energy transformations previously only possible in stars. Today, scientists and engineers continue to look for ways to control and sustain fusion reactions, which could someday provide a nearly inexhaustible source of energy for society.

*f. * Students know evidence that the color, brightness, and evolution of a star are determined by a balance between gravitational collapse and nuclear fusion.*

A major concept in science is that temperature is a measure of the underlying energy of motion of a system. Furthermore, thermal energy can be radiated away into space as electromagnetic radiation. This process produces the light we receive on Earth from the sun. With increasing temperature of a star's surface, the intensity of radiation produced increases, and the spectrum of radiation shifts toward shorter wavelength. Consequently, a blue-white star is hotter than a red star, and it emits more energy if the two stars are equal in size.

The surface temperature is a guide to the internal processes occurring in the star. Stars are so hot that they are a form of matter known as a plasma, in which atoms move so fast that electrons cannot keep up, leaving the nuclei free as ions. Gravity acts to collapse the ions in the hot plasma. The high density and high temperature of the plasma allow the barrier caused by the mutual repulsion of positive nuclei to be overcome, permitting fusion, or nucleosynthesis, to occur in the stellar core. The energy released by this reaction helps maintain a pressure that resists further compaction by the gravitational force and prevents collapse of the stellar core. The stellar dynamics evolve to a structure that reflects the thermal energy flow from the hot core, where energy is created, to the cooler surface, where it is radiated away to space as starlight. The star will attain an energy balance, so that the production of energy by fusion equals the upward heat flow, and this equals the energy emitted to space. The size and color of the star reflect the balances needed.

g. Students know how the red-shift from distant galaxies and the cosmic background radiation provide evidence for the "big bang" model that suggests that the universe has been expanding for 10 to 20 billion years.*

During the 1920s Edwin Hubble observed the red shift, (apparent increase in wavelength of emitted radiation) of distant galaxies. The red shift is due to a Doppler effect as distant galaxies are rapidly receding from ours. He noted that their speed of recession is proportional their distance, and suggested that the universe is expanding. More recent verification by radio wave and other data of the existence of a 3K background radiation, or low level microwave background "noise," throughout the universe has led to the acceptance of the "big bang" model of an expanding universe that is 10 to 20 billion years old. According to this theory, this radiation started as very high-energy short-wavelength radiation created by the explosion at the birth of the universe. As space expanded, and the universe cooled down, the wavelengths were essentially stretched out. A major breakthrough in astrophysics occurred in the 1990s, when scientists at the Lawrence Berkeley National Laboratory in California saw evidence for variation in the intensity of this background radiation. This is consistent with the idea that matter in the early universe was already starting to condense in some areas, a necessary first step toward the clumping together that led to the formation of stars and galaxies.

STANDARD SET 3: Dynamic Earth Processes

Background

Earth science utilizes concepts, principles, and theories from the physical sciences and mathematics, and often draws on facts and information from the biological sciences. To understand the earth's magnetic field and magnetic patterns of the sea floor, students will need to recall, or in some cases learn, the basics of magnetism. To understand circulation in the atmosphere, hydrosphere, and lithosphere, students should know about convection, density/buoyancy, and the Coriolis effect. Earthquake epicenters are located using geometric techniques. Understanding the formation of igneous and sedimentary minerals requires student mastery of concepts related to crystallization and solution chemistry. Because high school students may take earth science before chemistry or physics, some background information from the physical sciences needs to be introduced in sufficient detail. From earlier standards, students should know about plate tectonics as a driving force that shapes Earth's surface. They should know that evidence in support of plate tectonics includes the shape of the continents, the global distribution of fossils and rock types, and the location of earthquakes and volcanoes. They also should understand that plates float on a hot, though mostly solid, slowly convecting mantle. They should be familiar with basic characteristics of volcanoes and earthquakes, and the resulting changes in features of the earth's surface from volcanic and earthquake activity.

Description of the Standards

3. <u>Plate tectonics operating over geologic time has changed the patterns of land, sea, and mountains on Earth's surface.</u> As the basis for understanding this concept:

a. Students know features of the ocean floor (magnetic patterns, age, and sea floor topography) provide evidence of plate tectonics.

Much of the evidence for continental drift came from the sea floor rather than the continents themselves. The longest topographic feature in the world is the mid-oceanic ridge system – a chain of volcanoes and rift valleys about 40,000 mile long that rings the planet like the seams of a giant baseball. A portion of this system is the mid-Atlantic ridge, which parallels both the coasts of Europe/Africa and North/South America, half way between them. The ridge system is made of the youngest rock on the ocean floor, and the floor gets progressively older, symmetrically, on both sides of the ridge. No portion of the ocean floor is more than about 200 million years old. Sediment is very thin on and near the ridge. Moving away from the ridge, it thickens and contains progressively older fossils, also symmetrically. Mapping the magnetic field anywhere across the ridge system produces a striking pattern of high and low field intensity, in nearly perfectly symmetrical stripes. A brilliant piece of scientific detective work interpreted these "zebra stripes" as arising because lava had erupted and cooled, locking into the rocks the direction of the earth's magnetic field at the time of the cooling. The magnetometers that are used to measure the intensity of the local fields "see" both the magnetic signature of the rocks and the overall present-day field of the earth. Lavas cooled during times of normal polarity appear magnetically stronger because the field direction locked into those rocks as they cooled adds to the present day field direction. Lavas cooled during times of reversed polarity carry a magnetic signature that is opposite to the present day field and which partially cancels its local measured effect, so the magnetometer measures low total intensity. The "stripes" provide strong support for the idea of sea-floor spreading, since the lava in these stripes can be dated independently, and reversed polarity regions correspond with times of known geomagnetic field reversals. This theory states that new seafloor is created by volcanic eruptions at the mid-oceanic ridge, and this erupted material continuously spreads out convectively and opens and creates the ocean basin. At some continental margins, deep ocean trenches mark the places where the oldest ocean floor sinks back into the mantle to complete the convective cycle. Continental drift, coupled with sea-floor spreading, forms the modern theory of plate tectonics.

b. Students know the principal structures that form at the three different kinds of plate boundaries.

There are three different types of plate boundaries, based on their relative motions. Divergent boundaries occur where plates are spreading apart. Young divergence is characterized by thin or thinning crust and rift valleys, and if divergence goes on long enough it eventually develops into mid-ocean ridges, such as the Mid-Atlantic Ridge and East Pacific Rise. Convergent boundaries occur where plates are moving toward each other. At a convergent boundary, material that is dense enough, oceanic crust, may sink back into the mantle and produce a deep ocean trench as it does so. This process is known as subduction. The sinking material may partially melt, producing volcanic island arcs such as the Aleutians and Japan. If the subduction of denser oceanic crust occurs under a continent, a volcanic mountain chain such as the Andes or the Cascades is formed. When two plates collide and both are too light to subduct, as when one continent crashes into another, the crust is crumpled and uplifted to produce great mountain chains, such as the Himalayas now, or, long ago, the Appalachians. The third type of plate boundary, called a transform or parallel slip boundary, comes into existence where two plates move laterally by each other, parallel to the boundary. The San Andreas Fault in California is an important example. It marks the boundary between the North American and Pacific Plates, and runs from the Gulf of California northwest to Mendocino County.

c. Students know how to explain the properties of rocks based on the physical and chemical conditions in which they formed, including plate tectonic processes.

Rocks are classified by their textures and chemical compositions. The composition reflects the chemical constituents available at the time the rock was formed. The texture is an indication of the temperature and pressure conditions under which the rock formed. For example, many igneous rocks, which cooled from molten material, have interlocking crystalline textures. Many sedimentary rocks have fragmental textures. Whether formed from cooling magma, by deposition of varying sizes of sediment grains, or transformed by heat and pressure, each rock possesses identifying properties that reflect its origin.

Plate tectonic processes control directly or indirectly the distribution of different rock types. Subduction, for example, takes rocks from close to the surface and drags them down to depths where they are subjected to increased pressures and temperatures. Tectonic processes uplift rocks, so they are exposed to lower temperatures and pressures and to the weathering effects of the atmosphere.

d. Students know why and how earthquakes occur and the scales used to measure their intensity and magnitude.

Most earthquakes form as the result of lithospheric plates moving relative to each other. The crust is brittle, and breaks episodically in a “stick and slip” manner. Plate tectonic stresses build up until enough energy is stored to overcome the frictional forces at plate boundaries. An earthquake’s magnitude (e.g., Richter Scale) is a measure of the amplitude of its waves, which depends on the amount of energy that is stored as elastic strain and then released. Magnitude scales are logarithmic, which means that each increase of one point on the scale represents a factor of ten increase in wave amplitude, and a factor of about thirty increase in energy. An earthquake’s Intensity (Modified Mercalli Scale) is a subjective, but still valuable, measure of how strongly an earthquake is felt and how much damage it does at any given location.

e. Students know there are two kinds of volcanoes: one with violent eruptions producing steep slopes and the other with voluminous lava flows producing gentle slopes.

Violence of volcanic eruptions is a function of the viscosity of the lava involved in the eruption. All magmas contain dissolved volatiles, or gases, which expand and try to escape as the magma rises to the surface – much like the bubbles in a bottle of soda. Fluid lavas allow gases to bubble away relatively harmlessly, but those that are viscous trap the gases until large pressures build up and the system explodes. Viscosity of magma depends both on the temperature (cooler is more viscous) and composition (higher silica content is more viscous). Some lavas (rhyolitic and andesitic) are both cooler and more silica-rich, and therefore very viscous. These erupt violently, scattering volcanic fragments and ash widely. Viscous lava doesn’t flow very far, and builds up steep-sided volcanoes. Other lavas (basaltic) are relatively fluid and erupt quietly, producing great flows of lava that gradually build up gently sloping deposits (shield volcanoes).

f. Students know the explanation for the location and properties of volcanoes that are due to hot spots and the explanation for those that are due to subduction.*

The melting of silica-rich (granitic) upper-crustal rock produces viscous lavas. The melting of iron-rich (basaltic) lower crustal or upper mantle rock produces fluid lavas. Upper crustal rock may melt at subduction zones, and violent volcanic eruptions are common there. Lower crustal or mantle rock may melt at the mid-ocean spreading centers, where quiet, fluid eruptions are common.

Volcanoes may also arise from the activity of mantle plumes, which are long-lived "hot spots" deep in the mantle. Rock is locally melted within the hot spot and migrates upward through buoyancy to cut through the crust and feed volcanoes. As the magma rises, it melts other lower melting-point rocks in its path and incorporates them into the magma. If enough upper crustal rock is incorporated, as at Yellowstone Park in Wyoming, explosive volcanoes result. If only lower crustal rocks are incorporated, as in Hawaii, non-explosive volcanoes form. Hot spot volcanism occurs in chains, with the volcanoes systematically aging down the chain. This is extra evidence supporting plate tectonics. Volcanoes form when a particular piece of the crust is over the hot spot, and then die out as that part of the plate moves off.

STANDARD SET 4: Energy in the Earth System (Solar Energy Enters, Heat Escapes)

Background

Students know that energy is transferred from warmer to cooler objects. They are expected to know that energy is carried from place to place by moving material or in heat flow or as waves. They have learned that when fuel is consumed, energy is released as heat, which can be transferred by conduction, convection or radiation. They have also learned that the sun is the major source of energy for the earth. They have studied how heat from the earth's interior influences conditions in the atmosphere and oceans, and have considered the changes in weather that result from differences in pressure, temperature, air movement, and humidity.

Photosynthesis may have been covered in detail if the student has completed high school biology. Students who have completed high school physics and chemistry will also be better prepared to deal with energy transfer and absorption. To complete this standard set, it will be helpful for students to review the characteristics of the electromagnetic spectrum. Students should also review information presented in the 6th grade science standards related to dynamic earth processes to increase their awareness of the enormous amount of energy stored in the earth, both as original heat and as a product of radioactive decay, and the mechanisms that bring heat to Earth's surface, which are primarily mantle convection and some conduction. Students know that heat from Earth's interior escapes to the atmosphere by volcanic eruptions, hot spring activity, geysers and similar means. Although spectacular and energetic, these phenomena are localized and occur over a tiny percentage of the earth's surface. Beyond these readily noticeable losses of interior heat, internal heat disperses into the atmosphere slowly and relatively uniformly across the entire surface of the planet.

Description of the Standards

4. <u>Energy enters the Earth system primarily as solar radiation and eventually escapes as heat.</u> As a basis for understanding this concept:

a. Students know the relative amount of incoming solar energy compared with Earth's internal energy and the energy used by society.

Most of the energy that reaches the earth's surface comes from the sun as electromagnetic radiation, concentrated in the infrared, visible, and ultraviolet wavelengths. The energy incident to the surface of the earth by the daily illumination by the Sun outweighs all other sources of energy on the earth's surface. There is energy within the earth, some of which is primitive, or original, heat from the planet's formation, and some that is generated by the continuing decay of radioactive elements, but over short periods of time only a small amount reaches the earth's surface. The enormous amount of energy remaining within the earth powers plate tectonics.

Human societies utilize energy for heating, lighting, transportation and many other modern conveniences. Most of this energy came to earth as solar energy. Some has been stored as fossil fuels, the remains of plants that grew through photosynthesis**.** Fossil fuels, including oil, natural gas, and coal, provide the majority of energy used by contemporary society. This energy has been stored in crustal rocks over hundreds of millions of years, it is ultimately limited in extent**.** A U.S. household uses an average of about 1 kilowatt of power or 1000 joules of energy per second. The sun delivers almost this much power to every square meter of the illuminated side of the earth. For this reason, total energy use by humans is small relative to the total solar energy incident on the earth every day**,** but harvesting this energy economically poses a challenge to modern engineering.

b. Students know the fate of incoming solar radiation in terms of reflection, absorption, and photosynthesis.

The fate of incoming solar radiation, which in concentrated in the optically visible region of the electromagnetic spectrum, is determined by its wavelength. Longer wavelength (e.g., infrared) radiation is absorbed by atmospheric gases. Shorter wavelengths of solar electromagnetic energy, particularly in the visible range, are not absorbed by the atmosphere, with the exception of absorption of ultraviolet by the ozone layer of the upper atmosphere. Some of the incident visible solar radiation is reflected back to space by clouds, dust, and the earth's surface, and the rest is absorbed. Plants and other photosynthetic organisms contain chlorophyll that absorbs light in the orange, short red, blue, and ultraviolet solar radiation spectrum. The absorption of visible light is less for green and yellow wavelengths, the reflection of which accounts for the color of leaves. The plant uses this light energy for photosynthesis, converting carbon dioxide and water to sugar, which is used to support plant growth and cell metabolism. A byproduct of photosynthesis is oxygen. The amount of carbon dioxide in the atmosphere declines slightly during the summer growing season and increases again in the winter. The solar energy stored in plants is the primary energy source for life on Earth.

c. Students know the different atmospheric gases that absorb the Earth's thermal radiation and the mechanism and significance of the greenhouse effect.

Every object emits electromagnetic radiation that is characteristic of the temperature of the object. This is termed "blackbody" radiation. For example, an iron bar heated in a fire will glow red. At room temperatures, the radiation emitted by the bar is in the far infrared region and cannot be seen except with cameras with infrared imaging capability. The sun is much hotter than the Earth, so energy reaching the Earth from the sun has on average much shorter wavelengths than the infrared emitted back to space by the Earth. Energy reaching the Earth is mostly in the visible range, and a portion of this energy is absorbed and must be radiated back to space for the planet to achieve an energy balance. The Earth does this by emitting black body radiation, but because it is cooler than the sun, it radiates it as infrared. Certain gases, particularly water vapor, carbon dioxide, methane, and some nitrogen oxide pollutants, while transparent to visible light, absorb in the infrared. These atmospheric constituents thus admit energy from the sun but inhibit its loss back into space. This phenomenon is known as the Greenhouse Effect and these constituents are therefore called “greenhouse gases.” Without them, the earth would be a colder place to live. Human activity, such as the burning of fossil fuels, is presently increasing the concentration of greenhouse gases in the atmosphere. This buildup has the potential of significantly increasing global temperatures and affecting global and regional weather patterns. Predicting the precise long-term impact is difficult, however, as the influence of cloud cover and other factors is poorly understood.

*d.** *Students know the differing greenhouse conditions on Earth, Mars, and Venus; the origins of those conditions; and the climatic consequences of each.*

Atmospheric conditions are different on Mars, Venus and Earth. Venus, with a thick atmosphere rich in greenhouse gases, exhibits a much higher planetary surface temperature than Earth. Mars has a very thin atmosphere depleted in greenhouse gases, and therefore has little greenhouse warming. Also, the thin atmosphere and lack of oceans on Mars do not effectively store heat, so the planet experiences large temperature swings, high in the daytime and low at night.

The greenhouse effect is important to Earth’s climate. Without it the planet would be much colder and more like Mars. But if the concentration of absorbing gases is too high, trapping too much heat in the atmosphere, excessive heating could occur on Earth, producing global warming, and something closer to the climate of Venus.

Greenhouse gases, principally carbon dioxide, are building up in the earth’s atmosphere, due primarily to burning of fossil fuels for electricity and heat. Computer models of the greenhouse effect, resulting from projected build-up of greenhouse gases, have been developed and predict an increase in average global temperatures. If these models are accurate, the change predicted could have significant consequences on weather patterns and ocean levels. However, Earth’s climate system consists of a complex set of positive and negative feedback mechanisms that are not fully understood, and therefore predictions contain some uncertainty.

STANDARD SET 5: Energy in the Earth System (Ocean and Atmospheric Convection)

Background

Students know that the uneven heating of the earth causes air movements, and that oceans and the water cycle influence weather. They also know that heat energy is transferred by radiation, conduction and convection, and that radiation from the sun is responsible for winds and ocean currents, which in turn influence the weather and climate. They should have learned the concept of density, and have learned that warm less dense fluids rise and cooler and denser fluids sink (Grade 9 Std. Set 8). Students who have completed chemistry and physics know that water has high heats of crystallization and evaporation, and high specific heat (HS Chemistry Std. Set 7.d). Others will have to be introduced to these concepts. This knowledge provides a foundation of physical principles for a fuller understanding of energy flow through the earth system.

Description of Standards

5. Heating of Earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents. As a basis for understanding this concept:

a. Students know how differential heating of Earth results in circulation patterns in the atmosphere and oceans that globally distribute the heat.

The sun's rays spread unequally on the earth, heating the planet more at the equator and less at the poles. As surface heat is transferred to the atmosphere, circulation cells are created. For example, hot moist air at the equator rises, expands under reduced atmospheric pressure, the expansion leads to cooling that causes it to release its water as precipitation**.** This air moves either north or south away from the equator, and eventually descends to the surface, is compressed and thereby heated, and so arrives at the surface with low relative humidity. There are three such cycles (called cells) between the equator and each pole. This circulation is responsible for regulating the general pattern of rainfall on the Earth's surface, with wet climates under regions of ascending air (like the equator), dry climates at higher latitudes of 10-30°, wetter climates near latitudes of 45-65°, and dry climates at high latitudes.

Because the earth's axis is tilted with respect to the plane of its orbit around the sun, there is a difference in the amount of solar energy hitting Earth's surface on its two hemispheres, creating seasonal differences in temperature. These temperature differences result in thermally driven circulation patterns in the atmosphere and oceans (convection) that redistribute heat globally. Air currents also distribute heat absorbed in the evaporation of water when that water re-condenses as precipitation elsewhere. For these reasons, the equator is cooler and poles warmer than otherwise expected.

The ocean and atmosphere are a linked system as energy is exchanged between them. Ocean currents arise in part due to cool or more saline waters descending, causing circulation patterns to be set in motion. These currents also distribute heat from the equator poleward.

b. Students know the relationship between the rotation of Earth and the circular motion of ocean currents and air in pressure centers.

The earth rotates on an axis, and all fluid flow on or below the surface appears to be deflected by the "Coriolis effect," making right turns in the Northern Hemisphere and left turns in the south. This is a complicated phenomenon to explain to students, but can be nicely illustrated with a rotatable globe and chalk. Students can hold the globe head still and draw a chalk line from the North Pole to the equator and another from the South Pole to the equator. The result will be part of a great circle. Now draw the same line with the globe slowly rotating, and a curved line will result. Note that the faster the globe turns, the more profound the turning of the chalk line. It may also be helpful to compare this effect with "centrifugal force," another apparent force arising from an accelerating reference frame. Many good demonstrations of this are possible. Also point out to students that the airflow past a bicycle rider feels the same if the bicycle is still and the air moving, or vice versa. An observer standing on the earth feels the air moving, even if the relative motion arises because he and the earth are moving through the air.

Combining convective air or water flows with Coriolis turning produces circular currents. For example, when a region, or cell, of lower pressure (less dense) air exists in the Northern Hemisphere, higher-pressure air tries to flow toward it from all sides by convection. However, the Coriolis effect deflects these flows to the right, leading to a circular airflow, counterclockwise when viewed from above.

c. Students know the origin and effects of temperature inversions.

Normally, the atmosphere is heated from below, by the transfer of energy from the Earth's surface. This produces convection. However, the horizontal flow of air warmed over topographic highs can create a situation in which warm air above traps cooler air below. This situation is called a temperature inversion and effectively stops convection. The result of such a temperature inversion is stagnant air. In areas of high population density, or other sources of pollution, atmospheric pollutants (known as SMOG) may be trapped by the inversion.

In southern California, inverted air is a normal summertime occurrence. In summer, there is usually a cell of high-pressure air over the adjacent ocean area, which produces a persistent sea breeze from the ocean to the land**.** At higher levels, flow from the high standing deserts provides warmer air. The lower portion of this wind is cooled by its passage over water, and the air package arrives in Los Angeles cool on the bottom and warmer above –inverted. This inverted air is rapidly filled with pollutants and is in turn held in place by mountains ringing the basin.

d. Students know properties of ocean water, such as temperature and salinity, can be used to explain the layered structure of the oceans, generation of horizontal and vertical ocean currents, and the geographic distribution of marine organisms.

In low latitudes, water is warmed at the surface by the sun. Density differences force this water to flow to high latitudes, where it cools as it transfers thermal energy to the atmosphere. Cooling increases water density, so it sinks at high latitudes, flows back toward the equator at depth, and upwells toward the surface as it is warmed by the sun. This density-driven circulation creates a layered ocean structure at low and mid-latitudes, with warm, low-density water at the surface and cool, higher-density water at depth. Salinity also plays a role, as rapid evaporation in dry-latitude belts concentrates the salt, while inputs of fresh water from rainfall in wet climatic belts, river inflows, and melting of ice formed at high latitudes also influence salinity. Because water has a high specific heat, it is effective at transporting heat from the equator to the poles. Furthermore, the high specific heat helps buffer the Earth's surface against large daily or seasonal temperature changes. The solid phase of water, which is ice, is less dense than the liquid phase and thus floats. (Note that this unique property of water is important to life on earth.) Icebergs float long distances from their places of origin before they melt and add fresh water to the surface of the ocean.

Water is an excellent solvent for many ions and dissolved gases that are necessary for marine life. Ocean chemistry reflects the combined influences of ocean circulation and of marine organisms on biologically active compounds. Near the surface, water is oxygenated by photosynthesis and dissolved nutrients required by phytoplankton are depleted. The phytoplankton are eaten by zooplankton and their remains sink into the deep sea where they decompose. The decomposition enriches deep water in nutrients and depletes it in oxygen. Leading to a chemically stratified ocean. As deep water is upwelled into the surface zone, it carries abundant nutrients needed to sustain the phytoplankton growth. The distribution of marine life is influenced by these patterns, because organisms tend to follow and stay within zones that best supply their requirements for survival.

In addition to the density factors that drive ocean circulation, there is also a wind-driven circulation in surface waters. These surface and deep currents mix the oceans continuously, particularly at the surface. Ocean currents influence regional climates. For example, the Gulf Stream brings warm water to offshore northwest Europe and warms the climate in countries such as Great Britain. If these currents are shut off, climate can be severely affected.

A teacher may wish to demonstrate density currents by using containers of water heated to different temperatures. Food coloring may be used to dye hot water one color and cold water another. Students observe as the hot water is poured into the cold water, and vice versa. The demonstration may be further extended by adding table salt to make different salt concentrations in same and different colored water samples. Pour the more saline water into fresh water, and vice versa, and allow students to observe and report what happens.

e. Students know rain forests and deserts on Earth are distributed in bands at specific latitudes.

Latitudinal bands or zones of similar climatic conditions circle the earth. These are based on the large-scale convective air patterns described earlier, known as "Hadley cells." Basically, air rises at the equator and near 60 degrees north and south latitude, and sinks near 30 degrees north and south latitude and at both poles. Here, it is helpful if students understand the ideal gas law and also the notion of relative humidity – that cooler air can evaporate less water than warmer air. If they have not studied these topics, explain that sinking air is compressed because of gravity's pull on the overlying air.

Rising air expands and cools, and sinking air is compressed and heated, much as compressing air into a bicycle tire warms it. Warmer air can hold more moisture, so the air seems dryer as it falls. Therefore, deserts are common in bands of sinking air, and, conversely, there is high precipitation in zones of rising air, which supports lush vegetation (rainforests) there.

f. Students know the interaction of wind patterns, ocean currents, and mountain ranges results in the global pattern of latitudinal bands of rain forests and deserts.*

As air is warmed in the tropics, water is evaporated and the resulting warm, moist air rises and cools. When this moist tropical air cools enough it becomes saturated and precipitates water as rain. The once warm moist air is now dryer, cold, and heavy. This air is displaced to the north or south by rising currents of warm moist air. The cold dry air begins to descend and is again compressed and heated. When it reaches the ground, at about 30 degrees latitude, the warm dry air evaporates water from the ground, producing a desert. A similar pattern is seen farther north and south, where temperate rainforests exist at about 60 degrees latitude**,** reflecting the rising air there. The air sinks at the poles, and is warmed somewhat, but is still very cold and very dry.

Deserts are also found outside the latitudinal band of deserts. These are called rain shadow deserts. An example is the desert condition in much of Nevada to the east of the Sierra Nevada Mountains. Warm, moist winds blowing off the Pacific Ocean rise up over the Sierra Nevada Mountains, cooling and dropping rain on the forested westward side of the mountains. To the east of the mountains, the now dry air drops down to lower elevations, heats up, and evaporates surface water, producing a desert. Global weather and atmospheric circulation maps from the weather bureau are helpful in the study of this process. Such maps can be downloaded from appropriate Internet sites. Students may search an atlas for maps that show the distribution of deserts and rain forests, and compare these maps with global weather maps. Students can plot atmospheric and oceanic currents on a world map, and identify warm, wet regions and those that are cold and dry.

*g.** *Students know features of the ENSO (El Nino southern oscillation) cycle in terms of sea-surface and air temperature variations across the Pacific and some climatic results of this cycle.*

The ENSO cycle (*El Niño*, Southern Oscillation) refers to the observed relationships between periodic changes in the temperature and air pressure patterns of the equatorial Pacific Ocean surface and overlying air masses. These relationships change on a scale of several years and correlate with characteristic global weather climate variability. Data over several decades on sea surface temperature, for example near the coast of Southern California, can be compared with other weather and related records, such as rainfall totals in various places in the world or various agricultural indicators to see patterns develop.

STANDARD SET 6: Energy in the Earth System (Climate and Weather)

Background

This standard set is designed to focus students on the various factors that produce climate and weather. Since the water (hydrologic) cycle is fundamental to understanding weather, it would be well to review it here. In previous standard sets for lower grade levels, weather was introduced as a phenomenon, followed by an introduction to the procedures by which weather is observed, measured and described. Subsequently, weather maps were introduced and students should have learned to read and interpret topographic maps. Prior standards (Grade 6 and Grade 7 I. & E. standards) also call for students to have constructed scale models and made predictions based on accumulated evidence. It would be well to review the concept of pressure.

Description of the Standards

6. <u>Climate is the long term average of a region's weather and depends on many factors.</u> As a basis for understanding this concept

a. Students know weather (in the short run) and climate (in the long run) involve the transfer of energy into and out of the atmosphere.

Unequal input and absorption of solar energy causes differences in air temperature and therefore pressure, which generates wind. Solar influenced evaporation and precipitation of water determines the humidity of the atmosphere. Evaporation and precipitation also transfer energy between the atmosphere and oceans, because energy is absorbed when water evaporates and is released when it condenses. Climate is the long-term average of weather. According to one old saying, “Climate is what you expect, and weather is what you get.”

b. Students know the effects on climate of latitude, elevation, topography, and proximity to large bodies of water and cold or warm ocean currents.

Previous earth science standards covered the latitude dependence of rainforests and deserts. But there are other variables that can modify the climate in a particular region. For example, since air expands and cools when it rises, expected temperatures at high elevations are considerably less than they are at sea level or below. Mountains also affect local climate because of the rain-shadow effect described in the prior standard set, coupled with the direction of prevailing winds. The Indian monsoon cycle and the smaller scale Santa Ana winds are further examples of how mountains may influence weather and climate. Proximity to large bodies of water also can strongly influence climate. Large-scale warm and cold oceanic currents, for instance the cold Japanese Current off California and the warm Gulf Stream off the East Coast of the United States, exert regional controls on the climate of adjoining landmasses. Even more importantly, water has a very high specific heat, which causes it to remain within a relatively narrow temperature range both between day and night and from season to season. So regions near bodies of water have their climate “tempered,” or cooled during hot weather and warmed during cold weather.

c. Students know how the Earth's climate has changed over time, corresponding to changes in the Earth's geography, atmospheric composition, and other factors, such as solar radiation and plate movement.

Because Earth is dynamic, particularly with regard to long-term changes in the distribution of continents resulting from plate tectonic movements, our planet’s climate has changed over time. Some geologic eras were much warmer than today. At other times, much of the land was covered in giant ice sheets.

Millenia scale variations caused by astronomical factors such as changes in tilt of the earth’s rotational axis with respect to the sun or gradual changes in orbit shape also influence climate. The configuration of continental landmasses affects ocean currents. Climate is affected, episodically, by volcanic eruptions and meteorite impacts that inject dust into the atmosphere. Dust and volcanic ash reduce the amount of energy penetrating the atmosphere, thereby changing atmospheric circulation, rainfall patterns and Earth surface temperatures.

Variations in life in general, and human activity in particular, affect the amounts of carbon dioxide and other gases that enter the atmosphere. The effect of carbon dioxide and other greenhouse gases is discussed in High School Earth Science Std Set 4.d.

d Students know how computer models are used to predict the effects of the increase in greenhouse gases on climate for the planet as a whole and for specific regions.*

Scientists now know enough about what controls complex climatic variations to construct computer-generated climatic models both on global and regional scales. Such models can be used to make predictions about societal generation of greenhouse gases, and the potential for accompanying changes in global and regional mean temperatures. Computer-generated weather models have been improved and broadened sufficiently to be useful in exploring long-term changes in weather that border on climatic predictors. Specific models have been constructed to predict effects of ozone depletion and build up of greenhouse gases. Students can download current and historical weather data from the Internet, and use this information to explore for themselves whether a correlation exists between the weather data and greenhouse gas production. Student conclusions may be compared with computer-generated greenhouse models and interpretations published in scientific papers or posted on the Internet. However, they should be advised to expect contrary opinions as interpretations of the same climate data can widely vary.

STANDARD SET 7: Biogeochemical Cycles

Background

Students who complete high school biology/life sciences before earth sciences already will have learned about biogeochemical cycles. Other students should have been exposed to the concepts of life cycles, food chains and the movement of chemical elements through biological and physical systems in standards at lower grade levels. Students also should have studied chemical changes in organisms, and can be expected to know that photosynthesis uses solar energy to create the molecules needed by plants. In this standard set, students will learn that within the biogeochemical cycles, matter is transferred in food webs or chains between organisms. Matter can also be transferred out of these cycles to physical environments where the cycling elements are said to be held in reservoirs. Matter can be transferred back into biological cycles by physical processes such as volcanic eruptions and products of the rock cycle, particularly weathering.

Description of the Standards

7. <u>Each element on Earth moves among reservoirs, which exist in the solid earth, in oceans, in the atmosphere, and within and among organisms as part of biogeochemical cycles.</u> As a basis for understanding this concept:

a. Students know the carbon cycle of photosynthesis and respiration and the nitrogen cycle.

Carbon and nitrogen move through biogeochemical cycles. The recycling of these components in the environment is crucial to the maintenance of life. Carbon is incorporated into the biosphere from the atmosphere by photosynthesis. It is then released back into the atmosphere through respiration. Carbon dioxide in the atmosphere is dissolved and stored in the ocean as carbonate and bicarbonate ions, which are taken up by organisms to make their shells. When these organisms die, their shells rain down to the ocean floor, where they may be dissolved if the water is not saturated in carbonate. Otherwise, they are deposited on the ocean floor and become incorporated into the sediment, eventually turning into a bed of carbonate rock, such as limestone. Limestone may dissolve in acidic rain, to return carbon to the atmosphere as carbon dioxide, sending calcium ions back to the ocean, where they will precipitate with carbon dioxide to form new carbonate material. Carbonate rocks may also be subducted, heated to high temperatures, and decomposed, returning carbon to the atmosphere as volcanic carbon dioxide gas. Carbon is also stored in the solid earth as graphite, methane gas, petroleum, or coal.

Nitrogen, another element important to life, also cycles through the biosphere and environment. Nitrogen gas makes up most of the atmosphere, but elemental nitrogen is relatively inert and cannot be used directly by multicellular plants and animals. Nitrogen must be "fixed," or converted to ammonia by the action of specialized bacteria. Other bacteria change ammonia to nitrite and then nitrate, which can be used by plants as a nutrient. Eventually, decomposer bacteria return nitrogen to the atmosphere by reversing this process.

b. Students know the global carbon cycle: the different physical and chemical forms of carbon in the atmosphere, oceans, biomass, fossil fuels, and the movement of carbon among these reservoirs.

The global carbon cycle extends across physical and biological Earth systems. Carbon is held, temporarily, in a number of reservoirs, including the biomass, atmosphere, oceans, and in fossil fuels. Carbon appears primarily as carbon dioxide in the atmosphere. In oceans, carbon takes the form of dissolved carbon dioxide, and bicarbonate and carbonate ions. In the biosphere, it takes the form of sugar and many other organic molecules in living organisms. Some movement of carbon between reservoirs takes place by biological means, such as respiration and photosynthesis, or physical means, such as those related to plate tectonics and the geologic cycle. Carbon fixed into the biosphere and then transformed to coal, oil and gas deposits within the solid earth has in recent years been returning to the atmosphere by the burning of fossil fuels by humans to generate energy. This release of carbon has increased the concentration of carbon dioxide in the atmosphere. Carbon dioxide is a primary greenhouse gas and its concentration in the atmosphere is tied to climate conditions.

c. Students know the movement of matter among reservoirs is driven by Earth's internal and external sources of energy.

The energy to move carbon from one reservoir to another originates either from solar energy or as heat from Earth's interior. For example, the energy that plants use for photosynthesis comes directly from the sun, and the heat that drives subduction comes from the solid earth.

d. Students know the relative residence times and flow characteristics of carbon in and out of its different reservoirs.*

Carbon moves at different rates from one reservoir to another, measured by its residence time in any particular reservoir. For example, carbon may move quickly from the biomass to the atmosphere and back because its residence time in organisms is relatively short and the processes of photosynthesis and respiration are relatively fast. Carbon may move very slowly from a coal deposit, or fossil fuel, to the atmosphere because its residence time in the coal bed is long and oxidation of coal by weathering processes is relatively slow.

STANDARD SET 8: Structure and Composition of the Atmosphere

Background

Students have little direct background on the structure and composition of the atmosphere beyond what they have learned from the preceding Standard Set 7. If they have taken high school biology/life sciences before earth sciences they will know how organisms exert chemical influences on the air around them through photosynthesis and respiration.

Description of the Standards

8. Life has changed Earth's atmosphere, and changes in the atmosphere affect conditions for life. As a basis for understanding this concept:

a. Students know the thermal structure and chemical composition of the atmosphere.

The atmosphere is a mixture of gases, principally nitrogen (78 percent), oxygen (21 percent), argon (1 percent), and trace gases such as water vapor and carbon dioxide. Gravity pulls air toward the earth and the atmosphere becomes gradually less dense as elevation increases. The atmosphere is classified into four layers according to the temperature gradient. With increasing altitude, temperature decreases in the troposphere, increases in the stratosphere, decreases in the mesosphere and increases in the thermosphere.

The troposphere is the atmospheric layer that we live in and it is the layer in which weather occurs. The stratosphere is less dense than the troposphere but has a similar composition with the exception that it is nearly devoid of water. The other difference is that solar radiation ionizes atoms in the stratosphere and dissociates O_2 to form ozone, O_3. This process is important to life on Earth, because ozone absorbs harmful ultraviolet radiation that would otherwise cause health problems. Air in the mesosphere has very low density and tends to be ionized by solar radiation. The thermosphere is almost devoid of air and is the outermost layer of the atmosphere, receiving the direct rays of the sun. The thermosphere provides a good illustration of the difference between temperature and heat. Temperature is high there because the little heat absorbed is distributed among very few molecules, keeping the average energy of each molecule high.

b. Students know how the composition of the Earth's atmosphere has evolved over geologic time and know the effect of outgassing, the variations of carbon dioxide concentration, and the origin of atmospheric oxygen

The primordial atmosphere was driven away by strong solar winds during the early history of the solar system. This atmosphere was then replaced by a combination of gases released from the earth (outgassing), mostly through volcanic action, and by bombardment of materials from comets and asteroids. Chemical reactions through time, in the presence of water, changed the atmosphere's original methane and ammonia into nitrogen, hydrogen, and carbon dioxide. Lightweight hydrogen escaped, leaving a predominance of nitrogen. As life capable of photosynthesis developed on Earth, carbon dioxide was taken up by plants and oxygen released. The present balance of gases in the atmosphere was achieved at least by 600 million years ago. Small but important variations in the amount of carbon dioxide in the atmosphere have occurred naturally since then. Significant increases have been measured in modern times and attributed in large part to human sources such as the burning of fossil fuels.

c. Students know the location of the ozone layer in the upper atmosphere, its role in absorbing ultraviolet radiation, and the way in which this layer varies both naturally and in response to human activities.

The ozone layer in the stratosphere is formed when high-energy solar radiation interacts with diatomic oxygen molecules to produce ozone, a triatomic oxygen molecule. The ozone eventually converts back to diatomic oxygen by absorbing ultraviolet radiation. This absorption of ultraviolet radiation in the stratosphere reduces radiation levels at the earth's surface and mitigates harmful effects to plants and animals. The formation and destruction of ozone creates an equilibrium concentration of ozone in the stratosphere. A reduction in stratospheric ozone near the poles has been detected, believed to be a result of the release of chlorofluorocarbons (CFC's), such as those used as working fluids in air conditioners. The halogens in these CFC's interfere with the formation of ozone by acting as catalysts - substances that modify the rate of a reaction without being consumed in the process. As catalysts, a few molecules of CFC's can contribute to the elimination of hundreds of ozone molecules in the stratosphere. While ozone is beneficial in the stratosphere, it is also a man-made photochemical pollutant in the lower atmosphere. Students should be taught the importance of reducing ozone in the troposphere while maintaining its concentration in the stratosphere.

STANDARD SET 9: California Geology

Background

Students should already know that mountains, faults and volcanoes in California are a result of plate tectonics, and that flowing surface water is the most important agent in shaping the California landscape. The topics in this standard set can be covered as a separate unit or as part of a unit included in other topics addressed by the standards. A specific discussion of California earthquakes can be introduced in the teaching of Dynamic Earth Process, Standard Set 3.

Description of the Standards

9. <u>The geology of California underlies the state's wealth of natural resources as well as its natural hazards.</u> As a basis for understanding this concept:

a. Students know the resources of major economic importance in California and their relation to California geology.

Many of the important natural resources of California are related to geology. The Central Valley is a major agricultural area and source of oil and natural gas because of deposition of sediments in the valley, which was created by faulting at the same time as the Sierra Nevada was elevated tectonically. California's valuable ore deposits (e.g., gold) came to their locations during formation of large igneous intrusions, when molten igneous rock was injected into older rocks. Geothermal energy resources are related to mountain building and plate tectonic spreading or rifting of the continent.

b. Students know the principal natural hazards in different California regions and the geologic basis of those hazards.

California is subject to a variety of natural hazards. Active fault zones generate earthquakes, such as those associated with the San Andreas Fault system. Uplifted areas with weak underlying rocks and sediments are prone to landslides, and, for example, the California Cascade Mountains contain both active and dormant volcanoes. The erosion of coastal cliffs is an expected occurrence caused in part by the energy of waves eroding them at their bases. When earthquakes occur along the Pacific Rim, seismic sea waves, or tsunamis, may be generated.

c. Students know the importance of water to society, the origins of California's fresh water, and the relationship between supply and need.

Water is especially important in California because its economy is based on agriculture and industry; both of which require large quantities of water. California is blessed with an abundance of fresh water, which is supplied by precipitation and collected from the melting of the snow pack in watersheds located in the Sierra Nevada and other mountain ranges. This process ensures a slow runoff of water following the winter rains and snowfall. But the water is not distributed evenly. Northern California receives the majority of the rain and snowfall. Southern California is arid to semi-arid. The natural distribution of water is adjusted with the assistance of engineered projects that transport water in canals from the northern to southern part of the state.

d. Students know how to analyze published geologic hazard maps of California and know how to use the map's information to identify evidence of geologic events of the past and predict geologic changes in the future.*

Students who learn to read and analyze published geological hazard maps will be able to make better personal decisions with regard to the safety of business and residential locations. They will also be able to make intelligent voting decisions relative to public land use and hazard remediation. There is a wealth of information pertaining to this entire standard set that is readily available, much of it on the Internet. County governments have agencies that dispense information about resources and hazards, often related to issuing permits and collecting taxes. The California Division of Mines and Geology is an excellent state level resource. Federal agencies that supply useful information about California resources and hazards include the United States Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), and United States Army Corps of Engineers